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HEAT (AND OTHER MATTERS).

Die Principien der Wärmelehre, historisch-kritisch entwickelt. Von Prof. E. Mach. Pp. viii + 472. (Leipzig: J. A. Barth, 1896.)

PROF. MACH has conceived this treatise in much the same spirit as his "Mechanik." Both books are partly based upon his lectures: neither of them pretends to give a complete account of the subject in its details and applications. The aim is rather to describe the principal facts and the development of ideas, to explain their connection and to examine critically the principles which underlie the study of thermal phenomena.

The contents of the book may be roughly divided into three parts, of which the first two deal with heat and thermodynamics. In these the general arrangement is a compromise between the strictly historical method and that of the ordinary text-book; nowhere is any attempt made to secure the completeness and detail of a technical treatise. Subjects which have been fully discussed by other authors (such as thermo-chemistry and the dynamical theory of gases) are omitted, or only briefly referred to. In the first part the principal subjects treated of are thermometry, the conduction of heat, radiation, calorimetry and the calorimetric properties of gases. In each case there is a historical survey, followed by a critical discussion of the ideas involved in the development of the subject. The chapters on thermometry open in quite the orthodox way. We meet our old friends the three basins of water—cold, lukewarm and hot—and are warned of the danger of relying implicitly upon the uncontrolled verdict of our senses. In the next chapter (a critique of the idea of temperature) we are further warned that we have nothing to do with metaphysical ideas as to a "true" or "natural" scale of temperatures; the object of thermometry being to indicate the thermal state of a body by a number with reference to a scale which can be produced and reproduced with certainty and accuracy. Every distinct pyrometric method involves a different definition of temperature; and the temperatures measured by any one of these methods have just the same significance as numbers in an inventory. We now come to two chapters which give us a foretaste of the freedom of treatment in which the author indulges so fully in the last third of the book. In one of these he answers the questions, "What are numbers?" and "What are names?"; the other is devoted to a discussion of *Das Continuum*. We next follow the slow growth of quantitative conceptions as to the conduction of heat, beginning with the case of a bar heated at one end. First we have Amontons' incorrect assumption that the temperature increases proportionately to the distance from the cold end. Lambert has a clearer conception of the permanent state, and finds that the excess of temperature above that of the surrounding medium follows an exponential law: but the way in which he deduces the result is incorrect. Biot, making use of Newton's law of cooling, first gives a correct theoretical and experimental investigation of this case. The more general treatment of conduction is due to Fourier, whose "Théorie analytique de la Chaleur" has been of the greatest importance in the development and transformation of the methods of mathematical physics. Considered from the physical standpoint, Fourier's theory has the merit of not being based (as is the kinetic theory of gases) upon an hypothesis, but upon an assumption proved by experiment to be correct, viz. that the flow of heat is proportional to the rate of change of temperature along the line of flow. His mathematical treatment is highly original and exquisite in form. At the same time his work well illustrates the beneficial reaction of investigations in various branches of physics and mathematics. The way for Fourier had been prepared by the researches of Taylor and others on the vibrations of stretched strings and the nature of partial differential equations (the results of which are here reproduced in somewhat modernised form). In turn, the powerful methods which he devised for solving problems on the conduction and radiation of heat have proved invaluable in the study of electricity, diffusion and hydrodynamics.

Among the founders of thermodynamics, Sadi Carnot occupies an unique position—one which must be rather unintelligible to those who hold that this science owes its birth to the conception of heat as a "mode of motion." In 1798 Rumford published his "Inquiry," and came to the conclusion that heat "cannot possibly be a material substance." Soon afterwards Davy, from further experiments, had deduced that "heat . . . may be defined a peculiar motion. . . ." And long before these two experimenters there had been speculations to the same effect. Yet Carnot's "Réflexions sur la puissance motrice du feu" (1824) throughout assumes the materiality (or indestructibility) of heat. In his *Gedankenexperiment*, the reversible cycle, it is assumed that the heat lost by the working substance in one set of operations is precisely compensated by the amount absorbed in the other set. "Ce fait n'a jamais été révoqué en doute. . . . Le nier, ce serait renverser toute la théorie de la chaleur." In spite of this, of the incorrect definition of the third operation in the cycle, of the difficulty of accepting step by step his reasoning, his conclusions are correct, and his method has proved profoundly suggestive. How happy his choice of the reversible cycle was, we can only appreciate by considering the very imperfect state of knowledge at that time as to the thermal properties of bodies: by requiring that the working substance should finally be brought back to its primitive physical condition, he ensures that it shall contain the same amount of heat after the cycle as before, and thus skilfully avoids a gap which could not then be bridged. In 1834 Clapeyron recalled attention to Carnot's essay, and gave appropriate graphical and analytical expositions of his method; but he still adheres to the hypothesis of the invariability of the quantity of heat (gained and lost in the cycle), and does not advance the essential ideas beyond the stage in which Carnot left them. These ideas first fell upon good ground in our own country, and bore fruit in Thomson's remarkable paper, "On an Absolute Thermometric Scale," published in 1848.

In one respect fate did not deal kindly with Carnot. He admits (in words following those quoted above) that the foundations on which the theory of heat rests require careful examination, and that several experi-

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mental facts appear nearly inexplicable in the actual state of this theory; nevertheless, if we had only the "Réflexions" to guide us, we should have to regard him as an adherent of the caloric hypothesis. Carnot died of cholera in 1832, and some forty years elapsed before the publication of his note-book showed how his views had changed since 1824. We have only space for one extract.

"On peut donc poser en thèse générale que la puissance motrice est en quantité invariable dans la nature, qu'elle n'est jamais, à proprement parler, ni produite, ni detruite. A la vérité, elle change de forme, c'est-à-dire qu'elle produit tantôt un genre de mouvement, tantôt un autre; mais elle n'est jamais anéantie."

Then follows an estimate of the number of units of heat required for "la production d'une unité de puissance motrice"! One cannot help wondering what might have happened if he had lived a few years longer, or if his views had not remained so long hidden.

As it is, the subsequent development of thermodynamics has not been the work of one person or of one country. The chapters in which Prof. Mach traces its growth, are amongst the most interesting in the book. One of his titles—"Das Mayer-Joule'sche Princip"—recalls a controversy the echoes of which have not yet died away, and indicates his position with reference to it. That position is one which many of our countrymen will not willingly accept; any more than they would accept the statement made on p. 261—"Im Grunde ist der Weg, auf dem Joule zu seiner Entdeckung gelangt, sehr ähnlich demjenigen Mayer's." But it would be unfair to allow such brief quotations to lead to the inference that the author is unfair or influenced by national bias. On the same page he draws attention to the soundness of Joule's scientific method; points out that he never befogged himself with metaphysical considerations; and that his theories were always based upon or controlled by experiment. Nor can we justly apportion the credit due to Mayer without considering the circumstances under which he thought and wrote, or without realising how imperfect (see his correspondence with Bauer and Griesinger) was his knowledge of physics. In the technical skill, the clearness and completeness of Helmholtz's paper "Ueber die Erhaltung der Kraft," we have a complete contrast to Mayer's writings. After an account of the progress which thermodynamics owes to the researches of Clausius and Lord Kelvin, we have the following comparison of the manner in which they presented their investigations to the world.

"In his exposition, Thomson is always quite frank and straightforward in dealing with the difficulties which meet him, the course that he strikes out is always the shortest and simplest, his methods are perfectly clear, and the motives which guide him in his investigations are visible to every one. In Clausius's exposition, there is always a touch of ceremony and reserve. Often one scarcely knows whether Clausius is more concerned to make a statement or to suppress it. The principles of the subject, instead of being deduced from simple experiences, are built up on specially assumed fundamental propositions; these look as though they were more reliable, but do not really offer any greater security than the experiences which might have replaced them. He has, too, a predilection for creating new names and ideas, which are not always necessary. But none of these personal and unessential peculiarities can mar the respect which we feel for Clausius's work."

Further chapters are devoted to the principal propositions in thermodynamics, the absolute scale of temperature, the principle of energy, and the relation between physical and chemical progress.

Up to this point we have nothing but praise for Prof. Mach's treatise: it will do much to revive interest in a subject which has suffered temporary eclipse by the larger developments in recent times of electrical science. The style is clear and forcible, and a due sense of proportion is shown in the arrangement of the subject-matter. We admire his mathematical skill, his critical insight, and the fairness with which he endeavours to apportion praise. The student will find him a trustworthy guide, and the teacher will recognise the frankness of a colleague who knows where the difficulties are and does not slur them over.

To some the remainder of the book will be of equal interest, as it undoubtedly is original, and after the author's own heart. But the reader who has bargained only for a historical and critical exposition of the principles of heat and thermodynamics, may be excused for feeling that he has been betrayed. For in the last twelve chapters Prof. Mach takes the bit between his teeth, and roams at will over the domains of scientific thought, philosophy, psychology, the theory of cognition, language, æsthetics, metaphysics and mysticism. To say that there is a "manifest solution of continuity" between these and what precedes, would be incorrect; but the choice and arrangement of subjects is somewhat kaleidoscopic and bewildering. In the absence of any index, reference is difficult (though here we may be confusing cause and effect). When we want to refer to an ingenious suggestion for inducing sparrows to progress by running instead of hopping, we find it in a footnote to a chapter on "Die Sprache"; while an interesting observation on the suckling and weaning of children finds place in a footnote to a chapter on "Der Begriff." This term (Begriff) is defined in a previous chapter on "Die Vergleichung als wissenschaftliches Princip," in which the author also discusses the question, *Was ist eine theoretische Idee?* Perhaps the most highly variegated chapter is that on "Der Sinn für das Wunderbare."

The proofs of the book have not been carefully read. There are misprints in the German text, and still more in the English quotations and references. The diagrams are numerous and clear, but the half-dozen full-page illustrations are not a great success. Joule is represented by a coarse reproduction of Jeens' engraving. The portrait of Clausius seems to be the best. That of Lord Kelvin is the worst; at any rate, it is as bad as it well could be.

pv.

CELL-STRUCTURE AND REPRODUCTION.

The Cell in Development and Inheritance. By Edmund B. Wilson, Ph.D., Professor of Invertebrate Zoology, Columbia University. (Columbia University Biological Series IV.) Pp. xvi. 371. (New York: The Macmillan Company. London: Macmillan and Co., Ltd., 1896.)

ORIGINALLY produced as the substance of a series of lectures of a popular character upon the problems of individual development and inheritance, the book

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